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NOTES

ON THE

FOOD OF PLANTS

CUTHBERT C. GRUNDY

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NOTES

ON

THE FOOD OF PLANTS.

BY

CUTHBERT C. GRUNDY, F.C.S.

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PREFACE.

THIS book claims no originality. The utmost I have done in experimental research has been only as a follower in the footsteps of those who have gone before.

I have tried to give, in a few words, and in as clear and connected a way as I am able, a plain but carefully drawn outline of the form and manner in which food is obtained by plants.

This being the limit of my desire, I have ventured to omit points which, although interesting to the student, would be out of place in a simple sketch intended for the general reader.

I hope that even this tracing, faint as it is, may lead the reader to look further into the wonders of vegetable life, and here and there suggest individual observation and thought. In trying to follow such a path, although we may often go astray, we shall learn to more clearly see and more often think of what the small as well as the great things in nature show us, and shall not fail to gather everlasting flowers to cheer us on our way.

C. C. G.

It has for long been supposed that plants imbibe through their leaves aqueous vapour from the atmosphere. The results of recent experiments render this opinion decidedly questionable.

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NOTES

ON

THE FOOD OF PLANTS.

NOTE I.

THE IMBIBITION OF NUTRIMENT.

VEGETATION derives its beauty from the essentials of every true (and therefore beautiful) design; and of these the most noticeable is harmonious variety. Rambling through the fields and forests; looking here and there along the hedges, and between the moss-grown rocks, for flowers and ferns; wandering upon the richly-coloured moor and wild fell-side;

sauntering beside the margin of the lake or on the river's bank;—go where we will, endless diversity is seen in form, in size, in texture, and in colour. Seeds, leaves, flowers, and fruit are characteristic of the plant to which they belong; and even the size and tint of these on the same plant are various. By the aid of the microscope this diversity is found in the minutest parts; and chemistry reveals a series of substances scarcely less diversified in scent, taste, and chemical properties.

From these wonderful variations in plants, and in the substances they produce, one might be induced to think that a great number of elements of construction must be required; but on examination, we find that vegetation is dependent for its varied beauty and for the variety of its productions, not so much upon the diversity of, as upon its power of selecting and combining, the materials placed at its disposal.

The substances of which plants are composed, and those which they contain, when resolved into their constituents, afford a somewhat lengthy list of elements:—Carbon, nitrogen, oxygen, hydrogen, sulphur, phosphorus, silicon, fluorine, sodium, potassium, calcium, manganese, magnesium, aluminium, iron, chlorine, bromine, iodine; and seldom, and in very small quantities, barium, zinc, arsenic, copper; rubidium, cæsium, titanium, and other rare metals. All vegetable matter, therefore, however varied it may be in chemical and physical properties, consists of two or more of these simple bodies variously combined. But the substances of which vegetation is formed, and the divers bodies secreted by plants, are made up almost entirely of intercombinations of only four of these elements; namely, carbon, nitrogen, oxygen, and hydrogen. The quantity in which other simple bodies are or may be present is, comparatively, always very small; and although some of these are absolutely necessary to the healthy life of the plant, the majority of them is required rather as agents in the decomposition and assimilation of compounds of the four primary constituents, than as materials for either the construction of the plant or the formation of its products.

These simple bodies, in their relation to our subject, may be conveniently divided into two classes.

All must have noticed that when a plant, or any part of it, is burned in the open air, the vegetable substance, although greatly reduced in bulk, is not wholly consumed: when the combustion has been completed, there is still a residue; as in the remains of a wood fire, or at the burned end of a cigar. It is, therefore, evident that there are in the plant two divisions of matter which are easily separable by heat, the one division assuming under its influence the gaseous form, while the other is left behind as ash. By analysis, we find that the matter driven off by heat consists of compounds of carbon, nitrogen, hydrogen, oxygen, sulphur, and phosphorus; and since these are the ultimate principles of which organised substances are chiefly formed, the section embracing these simple bodies has been termed the Organic class, and that including the remainder, the Inorganic class, of the constituents of vegetable matter. This nomenclature is, however, one of convenience only; for while the whole of a plant must be deemed organic, all the food of vegetation is, in fact, inorganic, since it is all obtained from inorganic sources,*—the soil and the atmosphere. While adhering to the division so easily obtained, it is, therefore, well to avoid these terms, and to speak of the former as the volatile section, and of the latter as the ash, or as the non-volatile or cinerial† section, of vegetable matter.

With the exception of oxygen, the elements named above as the ultimate principles of vegetable matter afford no nutriment to vegetation, if given in their free state. To be used as food, it is necessary that the plant shall receive them in the form of certain compounds; and these compounds, moreover, to be acceptable, must be conveyed to the plant in the gaseous or fluid state, or in solution, for solid matter cannot enter the vegetable structure. Although many of the simple substances employed in the building up and sustentation of the plant, and in the formation of its secretions, are, as elements, solid, yet in combination they occur as gases, or fluids, or in solid compounds soluble in water.

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* An exception is found in the Fungi.

† *Cinis*, ashes.

Fluid and gaseous are also the vehicles which convey these compounds to vegetation. Plants being unable to go in search of food, water and the ever-moving air act as caterers, and bring to them an unfailing supply of nutriment; for the gases necessary to vegetation are always present in the atmosphere, and these and other materials required for the support of the plant, are found in the soil dissolved in water.

The means provided for the imbibition of sustenance correspond to each state in which it is brought to the plant. Water and the nutritious substances dissolved in it are absorbed from the soil by the roots; and the vapour of water and the gaseous food that is mingled with the air are imbibed from the atmosphere by the leaves and other green parts of the plant.

The absorption of nutriment from the soil is effected principally by the rootlets and the hairs upon them; for the tips and those parts of the root which have become dense on the surface have little or no absorbent powers.

The imbibition of gaseous food takes place through thousands of minute mouths (termed stomata or stomătes) in the skin of the leaves and other (green) parts; it is also through these apertures that gases and vapours not required by the plant find an exit (indeed this function is probably as important a one as the former; amongst other reasons, because the transpiration of water has a powerful influence on the absorption of fluids through the roots): and in order that the ingress and egress of aërial matter may be regulated, each mouth is bound by two or more elastic vesicles, which lessen and enlarge the opening as circumstances require.

This action is apparently dependent on the hygrometric state of the atmosphere, and on the strength of the sunlight to which they are exposed. Stomates vary in size and in the manner of arrangement. They are generally disposed irregularly, but at equal distances ; yet in some cases, as in grass, they are arranged regularly. They occur sometimes on both the lower and upper surface of the leaf, and on parts which are modifications of leaves, and on the stem ; but they are most abundant on the lower surface of the leaf. Their number, however, varies with the kind of plant. Thus on membranous leaves they are very numerous, for transpiration is here required to take place rapidly ; while on succulent leaves, where the evolution of vapour is comparatively limited, they occur somewhat sparingly. On leaves which float upon water, they are only found on the upper surface, and are generally altogether absent from the leaves of plants which grow under water. In many cases, the number of stomata on the square inch of a leaf amounts to tens of thousands.

The necessity for food being received in the fluid or gaseous state, or in solution, will be recognised by an examination into the elementary structure of the plant. Each part of all plants consists of cells or sacks, variations in the form, size, thickness, and arrangement of the cells giving structural variations. Where the cells are whole and merely clustered together in numbers, we have cellular tissue; where a number of cells have merged one into another so as to form a tube, we have a vessel; and bundles of these, with cells of various lengths about them, constitute vascular tissue. The active cells have porous walls, and are filled with fluid. In this fluid, in some cases, float granules of starch, or of chlorophyll (the substance which gives to plants their green colour), or globules of oil, or crystals: these substances have not, however, been received into the cell in the state in which we find them, but have been formed within the cell from matter supplied in the gaseous state or in solution. (The growth of the plant is effected by the cell-contents dividing, and a cell-wall growing up between the two, thus converting one large cell into two small ones. These small ones then grow to the full size, and each is in its turn split up into two small ones; they in like manner enlarging until they have attained the required size and form.)

Since, then, the plant is formed of closed vessels and cells, it is evident that solids cannot be transmitted through the vegetable organism—that the only form in which matter can circulate is either as a gas or in a state of solution. The transmission of gases and fluids is accomplished chiefly by osmose, a process which appears to depend for its action on capillary attraction. If we have a tube divided in the middle transversely by a porous membrane, and two miscible fluids (or gases) of different densities be placed, the one in the upper, the other in the lower half, we shall find that the fluids (or gases) will not remain in their respective chambers, but will pass through the membrane in contrary directions and become mixed; each half of the tube, at the completion of the movements, containing a fluid (or gas) of the same composition as that in the other half. This process has been found powerful enough to effect the decomposition of salts.

The leaves having withdrawn from the atmosphere aqueous vapour and the various gaseous compounds containing the required elements, and the roots having imbibed these and fixed matter in solution from the soil, these several substances are decomposed within the plant, and all or some of their constituents made use of in its nutrition.

Thus plants have to some extent the power of selecting suitable food. Not only every plant of the same kind, but also plants of every kind (having the means) imbibe the same compounds from the atmosphere, and make use of the same elements of these compounds. The quantity of the matter imbibed and assimilated varies, of course, not only with various kinds of plants, but also with different plants of the same kind, and with the same plant under varying circumstances.

The efforts that have been made to ascertain the extent of the plant's power of selecting mineral food from the soil have not been successful. Although some of the bases found in a particular plant are generally present in plants of the same kind, all the mineral matter in one plant does not always correspond with that found in another specimen of the same kind of plant. Plants of a particular kind usually contain one or more bases in a larger proportion than the rest; but if the most suitable matter be not within reach in a sufficient quantity, the plant may make up the deficiency by employing other convenient, but less suitable bases. In the latter case, however, the plant will not flourish as if it had a full supply of the most acceptable mineral food. Whatever the results of experiments for the elucidation of this point may be, they are, I believe, attributable to modifications of the same causes, namely—(1st) The quantity, (2d) The physical condition, and (3d) The chemical properties, of the matter already within the plant, and of that which is capable of being absorbed;

and (4th) Peculiarities in the structure of the plant employed.

It seems probable that matter which, although absorbed, is not assimilated, and is in no way required, will, soon or late, be ejected or allowed to escape. Through the stomata, such an emission does take place—as in the transpiration of water and the evolution of superfluous oxygen ; but the evidence as to the extent to which ejection is carried on through the roots, and what the character of such a process may be, is conflicting. It is not improbable that mineral matter, in a state of solution, exudes from the leaves and bark, and thus becomes washed away by rain. The exudation of gum and sugar supports this supposition.

NOTE II.

GROWTH.

WHEN the seed is placed into, or drops on to, the soil, the porosity of its tissues enables it to soon absorb water, and it increases in size. The percentage quantity of moisture taken up is different in the seeds of different kinds of plants.

The seed of mustard absorbs water to the amount of— . . . . . 8.0 per cent.

„	wheat	„	„	45·5	„
„	barley	„	„	48.2	„

The seed of turnip absorbs water to the amount of— . . . . . 51.0 per cent.

,,	rye	,,	,,	57·7	,,
,,	oats	,,	,,	59.8	,,
,,	hemp	,,	,,	60.0	,,
,,	kidney-bean	,,	,,	96.1	,,
,,	horse-bean	,,	,,	104.0	,,
,,	pea	,,	,,	106.8	,,
,,	clover	,,	,,	117.5	,,
,,	beet	,,	,,	120.5	,,
,,	white clover	,,	,,	126.7[*]	,,

The effect of this absorption of moisture is the conversion of some of the insoluble contents of the seed (starch, fat, fibrin) into soluble compounds (*e.g.*, sugar) capable of being made use of in the nourishment of the embryo; and the decomposition thus occasioned is supposed by some physiologists to set free a force which takes an active part in the germination of the seed. In the genial warmth of spring, the organs that are destined to be the means of obtaining food from without—from the atmosphere and from the soil—develop. By and by the testa or cover of the seed is burst, and the radicle, that part which will form the root, creeps out and passes downward into the soil; and the plumule, that part which will constitute the stem, and bear the leaves, the flowers, and the fruit of the plant, pushes upward to the light. What the unerring force or forces may be by which these parts are guided into the positions they are to occupy, has not been satisfactorily explained.

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[*] Hoffmann.

The rapidity with which germination takes place, and the strength of the plant in after-life, are much influenced by the degree of moisture and of heat under which this stage of the life of the plant is accomplished. If too much moisture be present, the seed will decay; if there be not a sufficient quantity of water, the physical and chemical processes necessary for the development of the young plant cannot take place. Extremes in temperature are also injurious. Too low a temperature retards or even prevents germination; too much heat kills the embryo. Sachs made a series of experiments on the germination of agricultural seeds in various temperatures; and he gives from 41°.0 Fahrenheit to 54°.4 Fahrenheit as the minimum temperatures at which the development can take place, and from 102°.2 Fahrenheit to 116°.6 Fahrenheit as the maximum temperatures above which the plant is killed. He considers a temperature between 78°.8 Fahrenheit and 93°.2 Fahrenheit to be that most favourable to the germination of agricultural seeds.

Light does not appear to be absolutely necessary at this stage of the plant's growth, but the chemically active rays of sunlight have in a remarkable degree the power of accelerating germination. The presence of air, however, cannot be dispensed with, for oxygen is required to effect the changes in the substances laid up in the seed which are necessary to the development and growth of the embryo. Oxidation in this, as in every other case, generates heat, and this probably has a beneficial influence on the development of the young plant.

During germination, carbonic acid (carbon dioxide combined with water), ammonia, nitrogen, marsh gas ("fire damp"), and carbon monoxide (carbonic oxide) are evolved: the results of the chemical processes going on within the seed.

Up to this point in the life of the plant no nutriment is obtained from without, save water from the soil and oxygen from the air. In the case of seeds scattered on the ground, the atmosphere supplies also moisture in the form of dew. The seed itself contains all other necessary food, including fixed or mineral matter.

By and by the plant puts forth its leaves, and the manner in which it obtains food is changed. It no longer gains sustenance from matter laid up within itself, but imbibes it by means of its newly-developed organs. The roots and rootlets insinuate themselves between the particles of soil, and while thus fixing the plant firmly in the ground, they suck up water and the nutritious substances which are dissolved in it. The fluids in the plant are denser than this solution, and a process of endosmose and exosmose is established, the imbibed solution passing inward through the cell-membranes in considerable quantities, and a lesser amount of the cell-contents moving in an opposite direction.

The fluid absorbed by the roots passes upward through the stem (especially through the newer wood), and in this condition is called the ascending or crude sap. Continuing its upward progress, it finds its way to the upper surface of the leaves, and, while flowing along their under surface, becomes affected by the absorption and emission of gases there at work under the influence of the sunlight. In its then altered state, it descends—in dicotyledonous plants—through the bark, where additional changes take place, and passes in a smaller quantity laterally through the medullary rays (through which the sap moves also when the bark has been removed from some part of the stem), its nutritive matter being the while assimilated in the nourishment of the plant; and, finally, that of it which reaches its starting-point, the roots, either passes out, being no longer required, or again ascends with the fresh fluid being there absorbed.

The course of the sap, however, is not altogether confined to fixed directions, but probably finds its way to any part of the plant where its contents are required. In the case of cellular plants—mosses, fungi, lichens, and seaweeds—it permeates each cell equally, and usually diffuses itself throughout the plant.

The elaborated sap is different in composition and appearance in different plants. It occurs clear, opaque, milky, or variously coloured; and while the sap contained in the cellular tissues is usually acid (on account of the presence of organic acids), and contains non-nitrogenous substances, such as sugar and starch, that found in the vascular tissues is alkaline, and contains large quantities of nitrogenous matter.

The movement of the sap is a subject which has attracted much attention, and many theories have been advanced in explanation of the cause of its progression. We are, however, still unable to speak with certainty on this point. It is probably dependent upon several causes, such as, in addition to action purely chemical—

1. The porosity of all vegetable tissues, and hence their capability of being permeated by fluids.

2. Exosmose and endosmose, which may be viewed as phenomena of capillary attraction.

3. *A vis a tergo,* exerted by the liquids being absorbed by the roots.

4. *A vis a fronte,* resulting from the transpiration of fluids through the stomates of the leaves.

5. Diffusion independent of osmose.

6. Expansion and contraction caused by changes in temperature.

7. The motion of the branches in the wind.

The movements amongst the granules in sap (first noticed by Schultz), most easily seen in plants in which the descending sap is milky, as in the celandine, is another subject of discussion; some physiologists viewing them as being analogous to those observed in the capillary circulation of animals, while others believe that these movements only occur when the containing vessels are injured.

Nourishment accumulates at particular points; and it is from these stores of nutriment that the materials for the construction of the flower are derived. (During the formation of the flower, oxygen is absorbed, carbonic acid emitted, and heat evolved, as at the time of germination.)

M. Faivre made for several years careful observations of the part played by the elaborated sap in the nutrition of the plant, taking for examination the white mulberry tree; and he arrived at the following conclusions:—The elaborated sap is not a transitory formation of the vegetable organism. In the mulberry tree, it is found at every time of the year in the trunk, the roots, and the twigs. If any one of these parts be diseased, if it cease to perform its function, as in the case of the leaves, the elaborated sap diminishes and disappears. It abounds in the inner layers of the bark, where great activity prevails, and it accumulates in large quantities at the base of each incipient bud, and in the limbus of the leaves during their growth. When cuttings are planted in winter in a hot-bed, those which have wood-buds, containing a large quantity of elaborated sap, scarcely contain any so soon as the buds have opened; so that the development coincides with a diminution in the quantity of the elaborated sap. The effects produced by the striking of the cuttings become especially perceptible when the twigs thus treated are compared with others taken from the tree at the same period and as nearly as possible in the same condition. The same results are not noticed in cuttings which are laden with fruit-buds.

It has been suggested by Mr Hunt that the germination of the seed in spring, the flowering of the plant in summer, and the ripening of the fruit in autumn, are severally dependent upon variations in the solar ray at these seasons.

If sunlight be allowed to pass into a dark room through a hole in the shutter, and then to fall upon a prism, behind which is stretched a sheet, the light will be seen divided into seven colours, namely (beginning at the top of the spectrum), violet, indigo, blue, green, yellow, orange, and red. These colours we may consider to be made up of the three primary ones, blue, yellow, and red; the other colours being formed of these in various combinations. Instead of dividing the ray into the seven prismatic colours, we may, by passing the sunlight through media of particular colours, deprive it of one or more of the three primary colours; and it is then found that the yellow rays, the blue rays, and the red rays have respectively distinct and characteristic properties. The yellow rays are those which give us light, the red are those which give us heat, and the blue are those which take an active part in chemical operations. By using coloured media, therefore, we are enabled to test the effect of different kinds of light on vegetable growth, and such experiments have given the following results:—

1. The effect of light which had permeated yellow media, and was thus deprived of all its

chemically active rays, was, in nearly every case, to prevent the germination of the seed, and in the few cases in which the seed sprouted, the young plant soon perished. Agarics and several varieties of fungi, however, flourished luxuriantly in this light.

2. In light which had passed through red media, and thus was deprived of light-giving rays, germination took place, if the seed were supplied with a quantity of water sufficient to compensate for the increased evaporation resulting from exposure to this warm light; but the plant was not healthy, and its leaves were generally white, showing that the production of chlorophyll was prevented.

Plants bend toward ordinary light, but when placed in light which has passed through red media, most plants turn away from it in a very marked manner.

Plants in a flowering condition may be preserved for a much longer time under the influence of red light than under that of any other; and it appears that such light is highly beneficial to the flowering process.

3. Light received through blue media, that is, the chemically active rays, had the power of accelerating in a very remarkable manner the germination of the seed and the growth of the young plant. But after a certain time, the length of time varying with nearly every plant subjected to the experiment, this light proved too stimulating, and growth proceeded at the expense of the strength of the plant. Seeds

at a depth in the soil at which they would not have developed under ordinary circumstances, germinated under concentrated activic force.

4. Light which had passed through emerald green media (*i.e.*, the light-giving rays only) accelerated the deposition of carbon, and the consequent formation of woody fibre. This light is required for the formation of chlorophyll.

As winter approaches, the action of the leaves becomes languid, and the leaves themselves change colour and fall off; the circulation of the sap almost ceases, and the whole plant is comparatively at rest. Thus it remains until revivified by the light and warmth of spring, when vegetation again bursts forth in a refreshened verdure, clothing the earth with the brighter mantle of another growth.

NOTE III.

THE ASH.

SOME plants are able to live for a long time suspended in the air without any attachment to the soil whatever, if they be supplied with rain-water. Bromelias, Tillandsias (both belonging to the Bromeliaceæ, herbaceous plants, remarkable for their dry, hard leaves), Orchidaceæ, and many species of Ficus, have been grown in this manner. A specimen of Ficus Australis lived thus for many years in the Botanical Garden of Edinburgh; and Dr

James M'Nab has cultivated Strelitzia augusta, currants, gooseberries, &c., suspended in the air, and supplied with water by means of a worsted thread; and some of the plants flowered and even ripened fruit.

By facts such as these, one might be led to believe that water and the food obtained from the atmosphere are of much greater importance to the plant than the substances obtained from the soil; and analysis, in some degree, encourages this idea. By carefully burning the plant, or any part of it, and comparing its weight before with that after the combustion, it will be found that the quantity of volatile substance is very much greater than that of the non-volatile matter. The difference is so great indeed, that weighing is not necessary, the reduction in the bulk of the vegetable substance being so large that the loss occasioned by the combustion at once attracts notice.* But the old opinion that mineral matter, found in vegetable substances only in comparatively very small quantities, is not necessary to the plant, but is merely accidentally present, although perhaps correct so far as regards those bodies which are sometimes absent and sometimes present in plants of the same kind, cannot now be entertained in relation to the whole of the non-volatile constituents of vegetable matter. Even in the case of plants reared from the seed without attachment to the soil, the growth, it must be borne in mind, is not accomplished without the aid of fixed matter, for mineral food is contained in the seed of all plants. Most plants, cultivated in this manner, therefore, flourish only for a limited time; that is, so long as the supply of non-volatile food obtained from the seed furnishes the required quantity of fixed matter.

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* A considerable part of the volatile matter is, however, obtained from the soil, as we shall see.

The specimen of Ficus Australis to which I have alluded as having been sustained for many years without any other nutriment beside that obtained from the atmosphere and rain-water, made but little progress in its curious position; the leaves gradually fell off, until the plant died.*

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* The following are the results of analyses of its leaves made by Dr John M'Adam :—

		Percentage quantity.	
		Volatile matter.	Ash.
Leaf stalk of former year's growth	contained	82.98	17.02
,, present ,,	,,	92.65	7.35
Leaves of former year's growth	,,	86.24	13.76
,, present ,,	,,	92.28	7.72

And in the instances of the plants cultivated by Dr M'Nab, the fact that some of them were able to bear flowers and fruit may be reasonably accounted for by supposing that the quantity of mineral food contained in the cells and tissues of the plants (some apparently unrequired fixed matter being generally found thus laid aside) was sufficient to render any fresh supplies unnecessary.

Analysis and observation prove beyond a doubt not only that fixed matter is of use to plants, but that it is an absolutely indispensable agent in the accomplishment of processes upon the results of which the healthy life of the plant, and, therefore, the proper performance of its assigned work, depend.

Of the actual part the mineral food takes in the operations of vegetable life, we have scarcely any knowledge whatever. Statements bearing upon this point are for the most part mere conjectures. We, indeed, know little even of the state in which mineral matter exists in the plant; for it must be remembered that analysis of the ash of vegetable matter does not, in all cases, by any means give us this information. The separation of the volatile from the non-volatile constituents of vegetable matter, and the subsequent processes by which the composition of the ash is determined, destroy the combination in which its elements existed in the living plant. Consequently, although by analysis we get a list of the elements of which the vegetable substance is composed, we cannot, in all instances, ascertain the state of combination in which they were present prior to our examination.

The quantity of ash varies in different specimens of the same kind of plant, and in different parts of the same plant; and these quantities vary with the age of the parts containing them. Generally, the amount of ash diminishes as the plant grows older; and it is found that the upper and outer parts (those, be it noticed, in which great activity prevails) usually contain more mineral matter than other portions of the plant. Two specimens of the same kind of plant, grown in soil of the same composition, contain different quantities of ash.

Seeds are the part of the plant in which the quantity of mineral matter is most nearly constant. The amount of fixed matter is different in the seeds of different kinds of plants, but the seeds of the same kind of plant have an almost constant quantity of non-volatile constituents. Seeds contained in pods, as in the case of the bean, have more fixed matter than those of wheat, rye, and other serials.

With the exception of nitrogen and hydrogen, ash may contain any of the elements given in the list in Note I.; but it is probable that the greater number of these are not necessary to vegetation, and the quantity in which these unnecessary constituents occur is exceedingly small. Salts of lime (calcium oxide), of soda (sodium oxide), of potash (potassium oxide), of magnesia (magnesium oxide), and of an oxide of iron (ferric oxide), may be considered to be requisite to the healthy life of nearly all plants; and with these, perhaps, may be included chlorine and silica (silicon dioxide). Lime is always present in agricultural plants, and in large amounts in the straw and leaf. It occurs in comparatively large quantities also in leguminous plants, such as beans, peas, clover, &c.; in the Cacti (where it is found combined with tartaric acid), and in lichens (in which it is met with in union with oxalic acid); and the crystals often contained in vegetable cells (either loose or in a distinct tissue hanging from the cell-wall, and various in size and shape), are frequently wholly composed of salts of lime—usually calcium oxalate and calcium phosphate. In the roots of Turkey and East India rhubarb, crystals of calcium oxalate are found to the amount of 25 per cent., and in the English plant they occur to the amount of about half this quantity. Crystals of the same salt abound in the cactus, and give great brittleness to its stem.

There are peculiar difficulties in investigating the relation of salts of soda to vegetation. Although soda is probably always present in some part of all plants (but often in mere traces), its quantity is exceedingly variable; and its presence in vegetable matter does not prove that it is necessary to plants, for it is almost impossible to find any substance in or on which this body is not detectable. It is remarkable that marine plants, surrounded as they are by water containing about 25 per cent. of sodium chloride, contain less soda than potash—salts of which occur in sea-water in very small quantities. Salts of potash, in large or small amounts, are present in the ash of all agricultural plants. The quantity in which potash is found in grains such as wheat, barley, rye, oats, rice, maize, &c., in peas and beans, and in carrots and potatoes, is comparatively large. In the ash of grains magnesia also is an important constituent, but in most cases its quantity is small. The amount of ferric oxide occurring in vegetable matter is usually quite minute; but this body is of great importance to plants, for it is believed to be required for the formation of chlorophyll, the green colouring matter peculiar to vegetation—a compound intimately connected with at least one important function of plants, namely, the imbibition and decomposition of carbonic acid.

Silica abounds in grasses, in straws, in reeds, and in Equisetaceæ. Equisetum limosum contains ·15.5 per cent. of ash, and of this 6.5 is silica. In the 23.6 per cent. of the ash of E. Telmatia, 12.0 of silica is found; and of the ash of E. hyemale, which equals 11.8 per cent., 8.7 per cent. is silica. Reeds contain so much of this hard substance, that in hot climates they are the cause of fire, for by striking together during a high wind the silica in their stems acts in the same way as the flint (which is impure silica) that is used to ignite tinder. This mineral is found in greatest quantity in the cuticle; and, as a rule, the amount increases with the age of the plant; but the quantity in which it is present is very variable. The quantity of chlorine occurring in vegetable matter also varies considerably; but it is, in one combination or another, present in all plants. It is usually met with in union with sodium or potassium.

Iodine and bromine occur principally in marine vegetation, which has the power of extracting from the water around them the compounds of these elements that are present in sea-water in very small quantities. It is from these plants we obtain the iodine and bromine of commerce, and in an amount we should be at a loss to get from any other source.

The qualitative composition of ash is now determined with wonderful power and accuracy by spectrum analysis. By an examination with the spectroscope the presence of such minute traces of substances may be detected, which, by the ordinary means of analysis, would remain undiscovered.—(See Professor ROSCOE'S *Lectures on Spectrum Analysis.*)

From the variety in kind and quantity of the inorganic substances of which different plants make use, it is evident that a particular soil may be better fitted for the cultivation of some plants than for that of others, or may be proper only for the growth of one kind of plant. For the same reason, when crops of one kind of plant are grown upon the same plot of ground for a number of years in succession, the soil is gradually deprived of the inorganic matter which this kind of plant requires; and unless an artificial supply of these particular mineral substances be given to the ground, the result is a deterioration in the quantity and quality of the crop of each successive year. The effect of thus exhausting the land by growing upon it many crops of the same kind is clearly shown in the table following, which exhibits the difference in the weight of crops of particular plants grown in the same plot successively for five years, and that of the same kind of crop grown each year in a different plot of ground :—

Crop.		'Average of five years in pounds.
Potatoes	in the same plot, . .	72.9
	in different plots, . .	92.8
Flax	in the same plot, . .	15.0
	in different plots, . .	19.9
Beans	in the same plot, . .	32.8
	in different plots, . .	34.8
Barley	in the same plot, . .	30.8
	in different plots, . .	46.5

Crop.		Average of five years in pounds.
Turnips	in the same plot,	10.4
	in different plots,	17.3
Oats	in the same plot,	28.0
	in different plots,	32.4

The principal cause of the difference here shown, between the crops grown for five successive years in the same plot of land and those of the same kind grown in different plots, must be the removal from the soil by the plant of the constituents particularly important to its growth (among which we must include ammonia), since other circumstances will probably be the same in both cases. The extent of this deterioration depends in a great measure on the description of crop, for in some cases only a few of the constituents are removed, or they are removed for only a short time; while in other instances, the produce of the land being taken to a distance, the soil loses its nutritive matter altogether.

This deterioration in the quality of land by the growth of several crops of the same kind leads to the adoption of what is termed a rotation of crops,—that is, the growing of a series of crops of different kinds in succession on the same plot of ground. Although the soil may be exhausted of the constituents required for the growth of one kind of plant, it may still be suitable for the growth of a crop of another kind,—particular plants requiring particular mineral food. Moreover, while the roots of one kind of plant penetrate not more than a few inches into the soil, the roots of another kind stretch out and pass down to a much greater depth, and are therefore capable of obtaining nutriment that is not within reach of the former kind of plant.

Soils are restored to fertility by one of two means,—either by allowing the land to lie fallow, or by making up the deficiencies of nutritive constituents of the soil by an artificial supply in the form of manure. By the first method (which was known and practised even so early as the Romans) time is allowed for the decay of vegetable matter, for the decomposition of mineral substances, and for the absorption of nutritious gases from the atmosphere. Ploughing, harrowing, and other farming operations assist, by allowing the atmosphere and the changes in weather to more easily and more quickly act upon the substances contained in the soil, and also, by dividing and mixing the soil constituents, to render the soil more nearly uniform and its substances more readily made use of by vegetation.

All bodies which are used to improve the soil, either in physical or chemical properties, are termed manures. Of those which are intended to give to the land the substances it lacks, farmers make use of a great variety. Thus we have farmyard manure (superior to any other kind), salts of lime, bones, salts of soda, ammoniacal salts, nitrogenous matter, soluble silicates, potash salts, guano, &c. Beside chemical manures (as such substances are called), there are what are termed physiological manures—such as oil, treatment with which has been found to greatly increase the growth of cabbages; and charcoal (of wood, of bone, or of peat), which has the power of absorbing and retaining gases useful to vegetation as food; and mechanical manures, which are employed to alter the physical condition of the soil, either to make it less dense—in order to allow air and moisture to enter more readily, and to enable the roots to insinuate themselves more easily—or to render the soil more compact, by doing which a better hold is given to the roots, and the too rapid evaporation of water is prevented. Sand is an example of the manures made use of for the former, and marl of those employed for the latter, purpose.

The consideration of the chemical composition of soils, as well as of their physical properties, and a knowledge of the substances made use of as nutriment by plants, ought to be possessed by every farmer who desires to carry on his agricultural operations on sound principles, and, consequently, with probable success; for he will then be able, in most cases, to account reasonably for the poorness of his crops, and to choose those manures which will best supply the deficiencies of the soil, whether they be the result of the growth of previous crops or a natural poverty of the land.

Soil is the result of the solution and subsequent deposition of mineral substances, the disintegration of rocks, and the decay of animal and vegetable matter; and since the formation and composition of the earth's crust and local circumstances are widely different in different parts, we find an almost endless variety in the soils of different localities. According to the quantity of clay (aluminium silicate), of sand (silica, more or less impure), of lime, and of vegetable matter in their constitution, soils are usually divided into six classes, namely:—

1. Argillaceous soils, which have little or no lime, and above 50 per cent. of clay.
2. Loamy soils, possessing from 20 to 50 per cent. of clay.
3. Sandy soils, containing not more than 10 per cent. of clay.
4. Marly soils, containing from 5 to 20 per cent. of calcareous matter (marls are those clays which are mixed with lime—calcium carbonate).
5. Calcareous soils, having more than 20 per cent. of lime—calcium carbonate.
6. Vegetable moulds, in which vegetable matter is plentiful.

The following table gives the comparative values of sixteen different soils. The results given are those of experiments extending over several years, and hence may be considered to be practically reliable:—

THE COMPARATIVE VALUE OF DIFFERENT KINDS OF SOIL.—(THAER.)

No.	Per cent. of clay.	Per cent. of sand.	Per cent. of carbonate of lime.	Per cent. of humus.	Value.	
1.	74	10	4½	11½	100	First class.
2.	81	6	4	8⅔	98	Strong wheat soils.
3.	79	10	4	6½	96	
4.	40	20	36	4	90	
5.	14	49	10	27	?	Rich light sand
6.	20	67	3	10	78	Rich barley.
7.	58	36	2	4	77	Good wheat.
8.	56	30	12	2	75	Wheat.
9.	60	38	...	2	70	
10.	48	50	...	2	65	
11.	68	30	...	2	60	
12.	38	60	...	2	60	Barley.
13.	33	65	...	2	50	
14.	28	70	...	2	40	
15.	23½	75	...	1½	30	Oats.
16.	18½	80	...	9½	20	

The fertility of land depends, however, not only on the quality of the surface-soil, but also, and in a great measure, on that of the subsoil, and on situation, &c.

NOTE IV.

THE VOLATILE CONSTITUENTS OF VEGETABLE MATTER.

EVERY substance contained in the non-volatile class, and the sulphur and phosphorus in the volatile division, are obtained by vegetation from the soil, and from that source only; while carbon, nitrogen, oxygen, and hydrogen, the materials required in greatest quantities, are received from both the soil and the atmosphere.

The atmosphere consists almost entirely of air, which is a mixture of oxygen and nitrogen in the proportions of about four-fifths nitrogen and one-fifth oxygen; the vapour of water, which is a compound of oxygen and hydrogen in the proportions of two of hydrogen and one of oxygen; carbon dioxide (a compound of one of carbon and two of oxygen) in union with water—that is, as carbonic acid; ozone, an allotropic modification of oxygen; and ammonia, which consists of nitrogen and hydrogen in the proportions of one volume of the former to three of the latter gas;—intermingled and always in motion. Although some of these gases are heavier than others, they do not rest in layers, one upon another according to their specific gravities; for gases which, under ordinary circumstances, do not combine, have the power of mingling together so as to form an even mixture. The heavy gas will pass upward if necessary, and the lighter gas downward, even though only a narrow tube connect the two. The consequence of this diffusive power of gases is, that volumes of the atmosphere, taken from different parts, close to the surface of the earth or at such heights as balloons have ascended to, have an almost constant composition. The advantage of this to vegetation is obvious, for plants being unable to go in search of food, it is absolutely necessary that the materials they require should be within reach; and it is therefore requisite that a *mixture* of these nutritious gases should be constantly flowing around them. Moreover, by the even composition of the atmosphere, plants growing high upon the mountain live in as fertile a neighbourhood, so far as aërial food is concerned (excepting the influence of local circumstances, and the effect of pressure upon gases, which is to bring their particles closer together, and thus inclose in a given space, in a low position, a greater weight of gaseous matter than would be contained in this space in a more elevated place), as those in lower situations.

Of the compounds from which plants obtain the elements of their volatile matter we will now speak individually; for although there is but little to tell of them in their relation to our subject, that little is full of interest on account of their importance to vegetation, and because they form links in the chain which binds together, in mutual dependence, the animal and vegetable systems.

The element carbon, from its great importance to the nutrition of plants, may be placed foremost amongst the simple bodies used in the construction of the volatile part of the vegetable structure.

The form in which this element is found most nearly pure is as diamond, and as such it is crystalline. As graphite, plumbago, or black-lead, it also occurs in an almost pure state, and sometimes in crystals, but of a different shape from those of diamond. In an amorphous state it is seen as lampblack and charcoal. In no instance, however, is carbon met with in any other condition than that of a solid, and as an element, therefore, it cannot be taken in by plants. It has, however, the power of forming gaseous compounds with oxygen, and it is from one of these oxides—namely, carbon dioxide—that plants obtain the carbon they require for the formation of their tissues. It is a colourless gas, with a pungent taste and odour, and is a narcotic poison. Even if much diluted with other gases, it quickly produces insensibility when inhaled; and if the inhalation be continued, death is the result. Its poisonous properties are exhibited in a cave called the Grotto del Cane, near Vesuvius, where this gas flows out of the earth and forms a pool (since it is about one-half heavier than air, and issues too quickly to be carried off by diffusion). Dogs sent into this cave, therefore, die in a very short time;

hence the name which the grotto has received.* In Java there is a valley filled in like manner with carbonic acid, as valleys are filled with the waters of a lake; and many animals, and even men, have lost their lives by wandering into it. This poisonous gas is produced whenever carbon burns in the air, and it is also formed in large quantities by the breathing of animals. At each inspiration we draw into our lungs a quantity of air, and this, coming into communication with the blood forced into the lungs by the heart, is deprived of some of its oxygen, it having combined with the carbon of the blood (as the oxygen of the air combines with the carbon of a burning coal); and thus the air when exhaled is deficient in oxygen, and laden with carbonic acid—the result of the combination. The effect upon the atmosphere, then, of the breathing of animals is to withdraw from it oxygen, and to charge it with a poisonous gas. It will therefore be readily understood, that were there not some agency at work counteracting the ill effects of respiration, the atmosphere would soon become so deficient in oxygen, and contain so large a quantity of carbonic acid, as to be fatal to animal existence. Such an agency is found in vegetation. The gas that is hurtful to us is required by plants as food; and through their stomata they take in the carbonic acid of the atmosphere—divide this, to us, poisonous gas into its constituents, oxygen and carbon—retain and assimilate the carbon, and return to the atmosphere the oxygen necessary for the support of animal life.

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* Part of this effect is probably due to the choking carbon dioxide produces when its inhalation in a pure state is attempted.

Animals and plants are thus rendered mutually dependent on one another. In breathing, we obtain the oxygen we require for the formation of the substance of our bodies—such as muscle, cartilage, &c.; for combination with worn-out matter, rendering it easy of removal; and for the support of that animal combustion by which the warmth of our bodies is chiefly maintained. One of the results of this is the production of a gas which, were it allowed to accumulate, would put an end to the existence that respiration supports; but instead of the evolution of carbonic acid being an evil result of breathing, it is the means of supplying food to plants, and, through their agency, of preventing the atmosphere becoming deficient in a gas we are every moment in need of, and upon the presence of which our very life depends.

By virtue of this co-operation the relative proportions of carbonic acid and oxygen in the atmosphere proper for the existing state of animals and plants are maintained. The quantity of carbonic acid in the normal condition of the atmosphere is comparatively small—usually about four volumes in 10,000 volumes of air,—a quantity sufficient for the use of vegetation, but not sufficient to have an evil effect upon animals breathing it.

The details of the means by which plants imbibe and decompose carbonic acid are not known; but there are certain conditions found to be necessary for the accomplishment of this important function of vegetable life, which it will be well to here enumerate, without attempting to explain the forces upon which their action is dependent.

Both for the inhalation and decomposition of carbonic acid by plants, sunlight is required—the light-giving rays, probably, since the actinic (or chemically active) rays, and those which give heat, have scarcely any decomposing power.

It is further necessary that the carbonic acid be diluted by nitrogen or hydrogen. In the atmosphere this dilution is effected by the nitrogen of the air.

The presence of the green colouring matter (chlorophyll) peculiar to vegetation appears to be closely connected with the process under consideration; for it is noticed that the power of inhaling and decomposing carbon dioxide is not possessed by fungi (such as mushrooms) and other pale plants. Chlorophyll* is found in the cells of the leaves and young bark; and it is here that the decomposition is supposed to take place. The presence of iron is required for the formation of this green colour, and sunlight is also necessary. Plants growing in the dark have pale leaves, and this is the case if they are grown in soils which contain no iron. If, however, plants in the first condition be brought into the light, and those in the second condition be supplied with iron, the leaves gain the green colour natural to them.

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* Chlorophyll has been decomposed into two substances, one of which (zanthophyll) possesses a yellow colour, and the other (cyanophyll) a blue colour.

Different plants, under like circumstances, effect the absorption and decomposition of carbon dioxide with different degrees of power. Aquatics are very vigorous in this respect.

It is remarkable that two sea-plants of a purple colour (Porphyra laciniata and P. vulgaris) accomplish this action with great rapidity.

The extent to which this important function is carried on is not dependent upon the number of leaves, but upon the area of foliage, its health, and proper exposure to air in motion, and to light. The bark of the young green twigs of the plant also take part in the work.

The assimilation of carbon is probably the result of *several* chemical processes, and it therefore takes place gradually and slowly; but the amount thus secured is very large. Carbon occurs in plants in a greater quantity than any other simple body. With the elements of water (oxygen and hydrogen) it forms a wonderful variety of vegetable compounds — such as starch, rosin, pectin (the jelly of fruits), gum, sugar, oxalic acid, acetic acid, malic acid, tartaric acid, citric acid. The fundamental substance of the vegetable structure—cellulose—contains much carbon (as may be seen from the composition of coal); and the quantity in which cellulose is present in the plant is only exceeded by that of water. Chlorophyll, the importance of which to plant (and animal) life has just been noticed, is also composed of carbon, oxygen, and hydrogen. Those plants which are used by us as food contain as much as from 37 to 50 per cent. of carbon. In fact, in every part of the vegetable organism, and in every kind of vegetable product, is this important element found.

Its presence in vegetable matter is soon rendered evident by imperfect combustion, since by this means the carbon becomes separated from its compounds, and blackens the burning mass, as in the charring of wood, the scorching of linen (which is almost pure cellulose), the toasting of bread, &c. If the combustion be complete, the carbon of the vegetable substance unites with the oxygen of the air, and again becomes carbon dioxide; and the volume of this gas thus formed is of course the same as that previously used by the plant for the construction of the substance burned.

That oxygen is evolved from the leaves during the day may be shown by placing a few that have been recently gathered from the tree under a bell-jar filled with water, and inverted in the pneumatic trough (or in a common basin of water), and exposing them to the action of the sun; for in a short time bright bubbles of gas will be seen studded over the leaves, and this, collected and examined, will prove to be oxygen. Under similar circumstances, sea-plants also give out oxygen, and some with great activity,—as the bright green Bryopsis plumosa, the common sea-grass (Enteromorpha compressa), the common green laver (Ulva latissima), Porphyra laciniata, and P. vulgaris.

Such plants are, therefore, employed with good effect in marine aquaria.

In the absence of light, plants inhale oxygen and evolve carbonic acid.

This, at first sight, appears to be equivalent to saying that the purification of the atmosphere, accomplished by plants during the day, is nullified by a contrary action during the night. But such is not the actual effect, for the quantity of carbonic acid absorbed in sunlight in a given time is much larger than that emitted during the same time in the dark. The experiments of De Saussure and Grischow indicate that the whole volume of the air in which the plant is kept in the dark undergoes diminution: hence it seems that the amount of carbonic acid evolved is less than that of the oxygen absorbed.

The absorption of oxygen during the night is due to the oxidation of vegetable substances deficient in this element, and is a purely chemical process, for it takes place in the dead as well as in the living plant. On the other hand, the evolution of carbonic acid may be attributed to a mechanical process. Imbibed during the day by the green parts of the plant, absorbed in solution by the roots, and dissolved in the juices of the plant; in the night it remains undecomposed, sunlight being absent; and as transpiration of the vegetable fluids takes place through the stomates, the acid gas is returned to the atmosphere in a corresponding quantity.

The amount of oxygen absorbed during the night is different in different plants. Fleshy plants take in a less volume in a given time than evergreens, and the latter less than those trees which lose their leaves in autumn. The leaves and other green parts of plants containing volatile substances absorb more oxygen than those which are without such matter. Thus the leaves of the white poplar (Populus alba), during twenty-four hours, imbibe twenty-one times their volume; those of the oak (Quercus Robur), containing tannic acid, fourteen times their volume; of the fir (Pinus Albies), which contain volatile and resinous oils, ten times their volume; while the tasteless and inodorous leaves of the Agave Americana absorb only eight-tenths their volume. Those leaves which are remarkable for the rapidity with which their green colour departs take in more oxygen in a given time than those whose colour is particularly durable. For example, the leaves of the poplar absorb eight times, and those of the birch nine times, their volume during the same time in which those of the holly imbibe only about eight-tenths (0.86) their volume—(DE SAUSSURE).

The power of absorbing oxygen is also possessed by fresh, moist wood, whether it be a twig or a piece from the interior of the trunk.

Carbonic acid is given off in large quantities, even in the daytime, during the periods of germination, flowering, and fruiting; but at such times its emission is due, not to mechanical, but to chemical, processes,—such as the conversion of starch into sugar. It is also evolved when the plant is in an unhealthy state. Such a plant has, therefore, a pernicious effect upon the atmosphere, and is unfit to be kept in an inhabited room. The same evolution takes place from a decaying plant. In both these cases it is due to the oxidation of the carbon in the vegetable substance.

It is by no means improbable that carbon dioxide is, moreover, exhaled during the day at other than the times of germination, flowering, and fruiting, or during disease or decay; since the amount of light received may occasionally be insufficient to effect the decomposition of the whole of the acid gas absorbed.

The supply of carbon to plants is increased by the roots, for they absorb carbonic acid in solution from the soil, to which it is brought dissolved in rain, and where it exists in combination with alkaline bases as soluble carbonates, and is also yielded by the decomposition of vegetable matter. The use of tillage is to mix the soil, and to allow the air to freely permeate the particles, in order to quicken disintegration and decomposition; and according to Liebig, the chief office of this process is to aid in the decay of humus, and thus increase the supply of carbonic acid.

In some localities vegetation is also indebted to volcanic action for an increase in the quantity of this nutritious compound, since in volcanic districts carbonic acid issues from fissures in the ground.

"Exhalations of carbonic acid gas are, even in our day, to be considered as the most important of all gaseous emanations, with respect to their number and the amount of their effusion. We see in Germany, in the deep valleys of the Eifel, in the neighbourhood of the Lake of Laach, in the crater-like valley of the Wehr, and in Western Bohemia, exhalations of carbonic acid gas manifest themselves as the last efforts of volcanic activity in or near the foci of an earlier world. In those earlier periods, when a higher terrestrial temperature existed, and when a great number of fissures still remained unfilled, the processes we have described acted more powerfully, and carbonic acid and hot steam were mixed in larger quantities in the atmosphere; from whence it follows, as Adolph Brougniart has ingeniously shown, that the primitive vegetable world must have exhibited almost everywhere, and independently of geographical position, the most luxuriant abundance and the fullest development of organism. In these constantly warm and damp atmospheric strata, saturated with carbonic acid, vegetation must have attained a degree of vital activity, and derived the superabundance of nutrition, necessary to furnish materials for the formation of the beds of coal constituting the inexhaustible means on which are based the physical power and prosperity of nations."*

Oxygen, as we have seen, is obtained by vegetation from air and from carbon dioxide;

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[*] Humboldt.

but the compound from which this element is got together with hydrogen in the greatest quantity is water—the result of the combination of these gases in the proportions of one of oxygen and two of hydrogen: the most abundant and most important of all chemical compounds. It is found in every part of the vegetable structure, and is present in a larger quantity than any other body; so great, indeed, is this amount, that, on an average, no less than three-fourths of the weight of the living plant is due to it. It is not only necessary as nutriment, but as a medium for the conveyance of other food, and to keep the various organs in a physical condition proper for the accomplishment of their functions. Moisture is as essential to the plant as light and air.

Deprive a plant of water, and do what we will to preserve its life, we shall fail. A plant that has been uprooted withers not so much because it is thus deprived of food it has hitherto obtained from the soil, but because it lacks a proper supply of water. It is no longer able to support its leaves; they droop and cannot perform the work for which they were put forth; a languor creeps over the whole organism, until, shrunk and faded, the plant becomes a mere shadow of its former size and shape, and soon dies. Again, the moisture which is required to maintain vegetable life is an active agent in the utter decomposition of the tissues of a dead plant, exerting a powerful influence in destroying the combinations of the various elements of which the vegetable organism was composed, and thus helps to prepare the food of other plants.

This important compound is ever present in the atmosphere, for it evaporates at all temperatures; and it is absorbed from this reservoir of aërial food along with other gaseous matter, as well as imbibed from the soil by the roots.

The manner in which dew is deposited is of itself sufficient evidence of the importance of water to vegetable life. During the day water is evaporating quickly; and although the bodies on the surface of the earth radiate heat then, as well as during the night, their temperature is kept higher than that of the air (which is heated mainly by radiation) by the direct action of the sun. When deprived of the sun's heat, however, the radiation, still continuing, cools these bodies, and they lower the temperature of the surrounding air, until the aqueous vapour in it is condensed and deposited on the earth as dew. But dew falls not alike on all substances. If on a dewy night we examine the gravel walk and the grass, we shall find that, although the grass is wet, the walk is comparatively dry. Dew falls in the greatest quantity on those bodies to which it is most necessary. Stones and other matter requiring no water, radiate heat slowly, and being, therefore, long in becoming cool, receive but little moisture; but the leaves and bark of plants radiate heat quickly, and, therefore, rapidly becoming cool, are bathed in dew.

Moreover, the texture of the leaf accords with the amount of dew necessary to the plant. Those which require little (as the holly) have hard, bright leaves; while the leaves of those plants by which much moisture is needed (as the hollyhock) are dull and rough.

Clear, calm nights aid the growth of vegetation, since, at such times, radiation takes place with facility, and, as a consequence, the deposition of dew is abundant.

Hydrogen, a colourless, tasteless, inodorous gas, is required for the formation of almost all vegetable substances, and this important element is obtained chiefly from water. In many compounds it is found in combination with oxygen in the proportions in which these gases form water; as in starch (carbon 6, hydrogen 10, oxygen 5), cellulose (C_6 H_{10}

O_5), sugar (C_{12} H_{22} O_{11}), &c.; hence one might conjecture that oxygen and hydrogen are employed directly in this combination, but it seems more probable that the water imbibed is first decomposed, and its constituents then re-united for the formation of the vegetable substance. How this decomposition is effected, however, is not known: it has been suggested that the alkalies absorbed in solution by the roots aid in the operation; but it is one of the most mysterious, and one of the most wonderful, processes accomplished by plants.

The quantity of water contained in plants is, as already stated, exceedingly large. The following table (compiled from determinations by Boussingault) gives the percentage amount of water lost by the several plants and seeds named, when dried at 230° Fahrenheit.

100 parts of	peas	dried at 230° Fahr. lose	8	parts of water.
„	clover seed	„	11	„
„	wheat	„	14	„
„	oats	„	15	„
„	rye	„	15	„
„	wheat straw	„	26	„
„	oat straw	„	28	„
„	potatoes	„	72 to 77	„
„	apples and pears	„	83 to 84	„
„	red beet	„	85	„
„	strawberries and gooseberries		90	„
„	sea-kale	„	92	„

The transpiration of water through the stomates takes place at all times, but the amount varies with circumstances, the principal cause of this variation being the state of the atmosphere. According to Hales, thirtynine superficial square feet of the foliage of the sunflower have been found to emit as much as twenty-two ounces of water in twenty-four hours.

De Saussure gives the following information respecting the effect of unripe fruits upon the atmosphere.

They have the same influence as leaves both in sunshine and in darkness, their action differing only in intensity, which is greatest in the leaves.

During the night, green fruits cause the oxygen of the air to disappear, and they replace it by carbonic acid, part of which they absorb. This absorption is generally less in the open air than in a receiver.

In the dark, they absorb more oxygen

when they are green than when they are ripe.

During their exposure to the sun, they extricate either wholly or partially the oxygen of the carbonic acid imbibed during the night, and leave no trace of this gas in their atmosphere. Several fruits detached from the plant thus added oxygen to air which contained no carbonic acid.

When their growth is very languid, they corrupt the air under all circumstances, but less in sunlight than in darkness.

Green fruits detached from the plant, and exposed to the successive action of night and day, alter the air but little either in purity or volume. The slight variations observable in this respect depend on their composition, which is modified by the degree of their maturity. Thus green grapes appear to assimilate a small quantity of oxygen, while grapes which are nearly ripe exhibit in their atmosphere entirely during the day the oxygen of the acid they exhaled in darkness.

This result, although not strongly marked, was constant in all De Saussure's experiments; and we may therefore conclude that the acidity of unripe fruits tends to fix the oxygen of the atmosphere, and that this acidity disappears as the oxygen is imbibed, the result of the process being sugar.

The inhalation of carbonic acid and other gases through the leaves probably ceases when the fruit has ripened, since the products of the processes dependent on their action are no longer required. The leaves of most plants then lose their green colour, and assume the beautifully varied tints peculiar to autumn foliage, and, falling upon the ground, decay, and are resolved into food for another growth. The change in their colour appears to be caused by the formation of acids, resulting from the union of the oxygen of the air with matter in the leaf; for it has been found that some leaves, after having lost their green colour, have been restored to their original colour by alkalies.

The elements carbon, hydrogen, and oxygen form, with their almost boundless capability of intercombination, a wonderful variety of substances, aërial, fluid, and solid, many of which are indispensable to animals and plants. They include some of the most important chemical compounds found in nature, and for the production of many we are indebted to plants, our never-tiring caterers. Among the compounds vegetation produces by the union of carbon, hydrogen, and oxygen, we have substances opposed to each other in many properties, although, so far as we know, identical in chemical composition. Under certain circumstances, one body, without a change taking place in the quantity of the several constituents of which it is composed, is resolved into a substance of quite a different character. It is conjectured that this change is the result of a re-arrangement of some or all of its elementary atoms—that by a varied disposition of the same number of atoms of the several elements constituting the compound, we obtain a change in the chemical and physical properties of the body thus acted upon. The power of effecting this wonderful alteration is possessed by vegetation, for plants are not only able to decompose a compound and re-combine its elements in a fresh combination, and to convert one compound into another by the addition or subtraction of one or more atoms, but also to act upon certain substances in such a manner that although their chemical composition remains unchanged, such an important alteration is occasioned in their constitution that their properties are no longer those by which they were characterised in their former state, but that they have become in chemical and physical properties new substances.

Of the many compounds which plants produce by the union of carbon, oxygen, and hydrogen, the most important are starch, cellulose, chlorophyll, various sugars, gums, fats, oils, and resins, and such organic acids as acetic acid, oxalic acid, tartaric acid, citric acid, and malic acid.

Starch is of great importance to vegetation, for it is one of its chief articles of food. Seeds contain compounds capable of being converted into soluble food for the nourishment of the embryo, and in most cases starch is the chief substance found thus ready for the use of the young plant. During the life of the plant this important body is often laid by as a store of food in the roots, in the underground stems, in the pith, and occasionally in the bark, the leaves, and the wood. Many tubers contain a large store of starch, as, for example, the potato, which yields starch in a more nearly pure state than any other plant. Carolina rice contains a larger amount of starch than any other grain, and great quantities are obtained from tropical trees, as sago from the sago-palm (Sagus Rumphii), tapioca from Jatropha manihot, and arrowroot from Maranta arundinacea. The starch thus laid aside is probably used little by little at all times, and it is also required for the formation of the flower and the seed, and for the nourishment of the plant in early spring. In one part or another it occurs in almost all plants, and from many it may be easily separated by crushing the vegetable substance (*e.g.*, potato tuber) and washing with water. The starch passes into the water as a soft, white powder, which, on examination, is found to be a congregation of organised granules,* the size and form being different in starch obtained from different plants.

When starch is subjected to a strong heat (to about 155° C.), we get an isomeric body—dextrine or British gum. This conversion is accomplished by plants at ordinary temperatures, apparently through the agency of a substance termed diastase, or of some other nitrogenous compound. Dextrine is convertible by vegetation, and by artificial means, into sugar.

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* An unorganised starch is met with.

Of sugars there are many kinds. One important and well-known kind is that obtained from the expressed juice of the sugar-cane (Arundo saccharifera), which is doubtless the honey that, as Strabo tells us, Nearchus said was obtained without bees from a cane growing in India. It is also contained in the sap of many forest trees, in grasses, and in beetroot, carrots, and many other plants. It is termed cane-sugar or sucrose. Another kind is the sugar resulting from the conversion of starch, called grape-sugar or dextrose, less sweet and less soluble in water than cane-sugar. We have also the sugar of fruits—levulose,—and others of less importance. After plants have formed sugar, and thus obtained a soluble food capable of circulation, they convert it into the insoluble matter of which their cells are composed. Of this matter the chief part is a substance having the same chemical composition as starch and dextrine—cellulose. This compound occurs in plants in a greater quantity than any body excepting water, and is the fundamental substance of the vegetable structure. It may be said to occupy the same position in plants as bone does in animals, since it is the firm, tough matter forming the skeleton which gives support and strength to the vegetable organism, and about which the rest of the vegetable matter congregates. It is tasteless, insoluble in water, tough and elastic. Examples are met with in fine cotton and linen, which are almost pure cellulose. Woody fibre consists nearly entirely of this body. Cellulose, like starch, is capable of being transformed into dextrine and sugar. (The remarkably explosive substance known as gun-cotton—trinitro-cellulose—is prepared by treating cellulose with a mixture of strong sulphuric acid and strong nitric acid.)

We need not dwell upon the other vegetable substances produced by the union of carbon, oxygen, and hydrogen. Oxalic acid is found in very many plants, and to some gives a decided acidity, as in the case of sorrel. It is often met with in union with lime or potash, and sometimes with soda. Calcium oxalate is insoluble in water, yet it is found dissolved in the cell-contents, as well as deposited as crystals. Tartaric acid is found in tamarinds, the pine-apple, &c.; citric acid gives the well-known acidity of lemons, currants, &c.; and malic acid is the acid of apples.

Among the compounds of carbon and hydrogen is the curious product of many trees of tropical climates, caoutchouc, or India-rubber, which when first extracted from the plant is a juice of a milky appearance, but soon gains the consistency that distinguishes it in the state in which it comes to us. Gutta-percha is another of these compounds, and is obtained also from trees of tropical growth. Of the same elements are composed the oils of turpentine (the product of the distillation of the crude turpentine of the pine and fir—cotophony or resin, a mixture of two isomeric acids, being left behind in the retort), of laurel, of bergamot, of juniper, of pepper, of lemon, and of orange.

The following formulæ express the composition of the chief of the compounds alluded to:—

Sucrose, or cane-sugar $= C_{12} H_{22} O_{11}$

$$\left.\begin{array}{l}\text{Starch}\\ \text{Dextrine}\\ \text{Cellulose}\end{array}\right\} = C_6 H_{10} O^5$$

Dextrose, or grape-sugar $= C_6 H_{12} O_6$

Tartaric acid $= C_4 H_6 O^6$

Malic acid $= C_4 H_6 O_5$

Oxalic acid $= C_2 H_2 O_4$

In addition to the carbo-hydrates (*i.e.*, substances composed of carbon, together with oxygen and hydrogen in the proportion in which they form water), and the other compounds mentioned above, we have a series of albuminous bodies, which, although occurring in plants in comparatively small quantities, are of great importance to vegetation and to animals; and for the production of these, nitrogen, sulphur, and perhaps phosphorus, are required, in addition to the three other elements of volatile matter—carbon, oxygen, and hydrogen. The three principal substances in this group are albumin, fibrin, and casein. From the difficulty of getting these bodies in a pure state, their chemical constitution is not accurately determined; but their percentage composition may be taken as being;—albumin—carbon = 53.4, nitrogen = 15.6, oxygen = 23.0, hydrogen = 7.1, sulphur = 0.9; fibrin—carbon = 54.3, nitrogen = 16.9, oxygen = 20.6, hydrogen = 7.2, sulphur = 1.0; casein—carbon = 53.9, nitrogen = 15.0, oxygen = 23.0, hydrogen

= 7.2, sulphur = 0.9; and perhaps a trace of phosphorus in each case.

These nitrogenous compounds are found in the juices of plants, but principally in seeds; and they are not only capable of yielding nutriment themselves, but appear also to assist in the conversion of other substances into soluble nutritious matter; and the power of vegetation of converting one compound into another, to which allusion has been made, is, doubtless, brought to bear on these albuminous substances with good effect, for they are capable of undergoing a variety of transformations.

The peculiarities of the albumin, fibrin, and casein found in plants may be observed by examining the corresponding animal compounds bearing the same names, for they are almost, if not quite, identical in chemical and physical properties. The white of egg is albumin more or less impure; the curd of milk (when precipitated by acids) is chiefly casein; and the fibre of muscle is fibrin. Vegetable albumin may be obtained from the juice of a grated potato, by first allowing the liquid to stand until the starch it contains has settled, and then heating the clear juice, when the albumin, in an impure state, separates out. By adding an acid to the clear liquid got by soaking crushed peas in hot water, vegetable casein is precipitated; and the well-known gluten got by working dough in water is impure fibrin, together with fatty matter and a little starch.

The nitrogenous compounds, like all other vegetable products, are not only of importance to plants, but also to animals. They are required for the formation of the animal organism. While starch and other non-nitrogenous matter are chiefly used by us for the production of the fuel by the combustion of which the warmth of our bodies is in a great measure maintained, the albuminous substances are necessary for the construction of flesh and other animal matter, such as bile, cartilage, &c.

The consideration, then, of the source from which vegetation obtains nitrogen, is a matter of no less importance (in its economic relations as well as in relation to plant life disconnected from our own) than that of the sources whence are obtained by plants the other elements of vegetable substances of which we have already spoken. Nitrogen—a colourless, tasteless, inodorous, non-poisonous gas, incombustible and incapable of supporting combustion—constitutes nearly four-fifths of our atmosphere, where it exists uncombined. By virtue of its negative properties it is well suited to dilute, and thus modify the great chemical activity of, the oxygen of the air; and in its character of a dilutant, it is of great use to both animals and plants, since without the presence of this or other inactive gas in the atmosphere, oxidation would take place so rapidly as to soon put an end to all life; and to vegetation, in addition to this service, it is necessary for the accomplishment of the imbibition and decomposition of carbon-dioxide.

According to some physiologists—Priestley, Ingenhouss, Ville, and others—plants make use of the free nitrogen of the air for the formation of their nitrogenous compounds; but the experiments of De Saussure, Boussingault, Woodhouse, Sennebier, Lawes, and others, lead to an opposite conclusion; and it is now generally admitted that vegetation has not this power. Apart from what experiments demonstrate, the former opinion seems unlikely to be correct, for although the free oxygen of the atmosphere is employed by plants in the formation of their compounds, and notwithstanding their marvellous powers of synthesis, it is hard to believe that they are able to overcome the remarkable antipathy to direct combination which characterises nitrogen. Moreover, were the imbibition and assimilation of the free nitrogen of the air actually in operation, would it not be in opposition to the economy of nature, so far as we understand it? The presence of a large volume of nitrogen in the atmosphere is necessary for the continuance of life, and if vegetation were day by day assimilating this gas, the normal and necessary composition of the atmosphere would—(no natural supply of free nitrogen having been provided)—be quickly and for ever destroyed, and, as a consequence, man would cease to exist; vegetation, then the destroyer, instead of, as now, the supporter of life, would degenerate and quickly pass away; and the earth would become a barren wild.

There can be little doubt that this important element is received in a state of combination;

and the observations alike of chemists and agriculturalists point to ammonia as, at all events, the chief source whence plants obtain their nitrogen. Ammonia is a compound of nitrogen and hydrogen in the proportions of one volume of nitrogen to three volumes of hydrogen. It is a colourless gas, with a very pungent odour, strongly alkaline, very soluble in water—one volume of water dissolving about seven hundred volumes of ammonia—and forms a soluble salt with almost every acid. It is generated when nitrogenous animal or vegetable matter putrefies, the nitrogen and hydrogen contained in these substances entering into combination during the process of decay, and as the ammonia thus formed is exceedingly volatile, it at once mingles with the air, unless absorbent substances, or those with which it readily unites, be present. The atmosphere, therefore, contains a small quantity of ammonia (about one in 1,000,000 of air), and it is doubtless imbibed by plants through their stomates along with other gaseous food, but the greater amount is probably received in solution through the roots. Notwithstanding its volatility, it is contained in the ground, for many of the constituents of soil have the power either of retaining it by virtue of chemical affinity, and thus forming non-volatile salts of this body, or of absorbing it apparently independently of chemical action. Charcoal is capable of absorbing no less than ninety times its own bulk of this gas, and the ammonia can be separated by simply wetting the charcoal with water. The humus (decaying woody fibre) in the soil possesses a similar power in a less degree. When completely dried, it absorbs seventy times its own bulk, so that it retains the ammonia generated by the putrefaction of nitrogenous matter in the soil, besides collecting it from the atmosphere, and parts with it for the use of vegetation when moistened by a shower of rain. Clay also has the power of retaining ammonia. A small quantity of this nutritious compound is also carried down to the soil dissolved in rain, often as ammonium carbonate, and sometimes in combination with nitric acid (formed by the passage of lightning through the air, by which means the oxygen and nitrogen are made to combine)—that is, as ammonium nitrate. But although the quantity of ammonia required by vegetation is not large, it is in the case of cultivated plants, especially those which are required as food, generally necessary to increase the natural supply of this body by adding an ammoniacal manure to the soil. Peruvian guano is an important body used for this purpose. It is composed of large quantities of organic matter and ammoniacal salts (sometimes 50 per cent.), together with water, calcium phosphate, magnesium phosphate, potassium chloride, and other alkaline salts, and insoluble matter, chiefly sand, and, when good, is capable of yielding 18 or 19 per cent. of ammonia. This is a very effective and concentrated form of manure, for almost the whole of its constituents are highly nutritious, the phosphates and other salts being of great value to plants. Urine is another powerful manure, since it also contains nitrogenous matter rejected from the animal system, and this, on putrefying, yields a large quantity of ammonia, which enters into combination with acids that are present; and, in addition to this, it contains alkaline and earthy phosphates. A very nutritive form in which to supply ammonia to vegetation is as ammonium sulphate. The fertilising effect of gypsum (calcium sulphate) strewn over a field may be in part attributed to its power of converting the volatile ammonium carbonate which falls to the ground dissolved in rain into the non-volatile ammonium sulphate. In this double decomposition calcium carbonate is formed, a salt scarcely at all soluble in pure water, but readily soluble in water containing carbonic acid.

Soot is another body employed to increase the supply of ammonia to plants. Being carbon in a very finely divided state, it absorbs the ammonia generated when coal burns, and also collects it from the air. In the manufacture of coal-gas, the ammonia produced is removed as an impurity by allowing the gas to pass through water, and this water, "gas liquor," as it is termed, is used, in a much diluted state, as an ammoniacal manure in the neighbourhood of gas manufactories.

Daubeny is of opinion that ammonia (together with carbonic acid) is received by vegetation from exhalations resulting from volcanic action. It is to this cause he attributes the continued fertility of Terra di Lavoro, and other parts of Italy; and to the same source traces the abundance of gluten in the crops, as evidenced by the excellence of Italian macaroni.

According to Hoffmann, ammonium nitrate is probably formed during all processes of slow oxidation, as, for example, that of humus in the soil. Schönbein discovered that this salt is formed whilst phosphorus is slowly oxidising.

From the beneficial result of using sodium nitrate (sometimes called Chili saltpetre) as a manure in the cultivation of some crops, especially those of grain, in which nitrogenous compounds are comparatively abundant, and other salts of soda not having this effect, it is conjectured that the plants obtain nitrogen from the nitrogen oxide contained in this salt; and, from what experiments have shown, we may conclude that nitric acid is a source of nitrogen to vegetation, although the quantity of this compound available for the nutrition of plants is much smaller than that of their other nitrogenous food, ammonia. Nitric acid is found in the atmosphere in small quantities, but, like ammonia, it must be chiefly received from the soil, where it is met with in combination. In the decomposition of nitrogenous matter in the presence of potash, nitric acid is formed.

It is probable that in the nutrition of the plant its ammonia and nitric acid are not directly assimilated, but are decomposed, and their elements re-combined. How their decomposition is accomplished is not known.

In addition to nitrogen, the albuminous

compounds contain, as already stated, sulphur. There can be little doubt as to whence plants obtain their supply of this element, for the atmosphere contains scarcely appreciable traces of hydrogen sulphide (sulphureted hydrogen—the gas which gives to rotten eggs their unmistakable smell), and this is the only sulphur compound present, if we except the sulphurous and sulphuric acids met with in the neighbourhood of towns, generated in the combustion of coal. But the soil contains many sulphates (salts of sulphuric acid), and these are, we may conclude, the compounds from which vegetation derives its sulphur. This opinion is supported by the fact, that in almost every sample of spring-water examined, sulphates are found. Of these, calcium sulphate (gypsum, a substance used as a manure), although only slightly soluble in water, is the most abundant. In order to fix the ammonia generated during the decay of the nitrogenous matter in farmyard manure, the heap is often sprinkled with sulphuric acid, and by this means a highly nutritious compound is formed — ammonium sulphate. This salt is employed in large quantities as an ammoniacal manure.

Sulphur compounds are contained in all the ordinary forms of vegetation ; and many plants, as garlic, onions, scurvy-grass, horse-radish, and the seeds of black mustard, are indebted to their presence for peculiarities in odour and taste.

Suphuric acid is an ash ingredient, since although some of the sulphur of the plant escapes when the vegetable matter is burned, part of it becomes oxidised during the combustion, and combines with some of the bases present.

In analyses of the albuminous bodies traces of phosphorus are found, but it is doubtful whether this element is to be viewed as a constituent of these substances or as an impurity. It occurs in some of the vegetable oils.

As a simple body, phosphorus is a solid, somewhat resembling wax, and is very inflammable, burning with a bright flame, and thus, combining with the oxygen of the air, generates phosphoric anhydride, which with water forms the important compound phosphoric acid.

This acid, in union with lime, magnesia, potash and soda, is usually found in the ash in large quantities, and there can be no doubt that it is, in one combination or another, of great importance to vegetation. According to Schumacher, potassium phosphate is of use to plants by aiding in the diffusion of albumen. The acicular crystals found in vegetable cells often consist of calcium phosphate, and this and other salts of phosphoric acid are present in seeds.

It is from vegetation that animals obtain the phosphates (and other salts) necessary for the formation of bone, to which such mineral matter gives hardness and firmness. Bones contain about 50 per cent. of tricalcium phosphate, and are, therefore, much used as a manure for soils deficient in salts of phosphoric acid. (The beneficial effect of bones* is in part due to the presence of organic matter capable of yielding ammonia.) Animal charcoal and bone ash are used for the same purpose, and in addition to these, a number of other phosphatic manures are now prepared in large quantities; such as powdered coprolites, apatite, and "super-phosphate of lime" (calcium hydrogen phosphate), each of which contains a large percentage of phosphorus pentoxide.

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* Percentage composition of bone :—

Animal matter	33
Magnesium phosphate	1
Sodium chloride	1
Calcium carbonate	11
Tricalcium phosphate	53
Calcium fluoride	1

NOTE V.

CONCLUSION.

SOME plants, instead of bein [illegible] in the soil, are attached to ot [illegible] fro [illegible] which they obtain, either wh [illegible] their nutriment. Of this para [illegible] there are two kinds, the first of [illegible] themselves in the inside of (livi [illegible] plants, and are consequently terme [illegible] parasites; and having, for a time, t [illegible] push [illegible] surface. These are [illegible] some [illegible] well known under th [illegible] of mildew, smut, dryrot, &c. Those of the second division are called superficial parasites, since they originate upon the surface of plants. Having germinated there, the radicle penetrates the bark, and thus establishing a connection with the interior, the parasites withdraw for their own nourishment some of the sap of the plant on which they live. This division includes two kinds of parasites — 1st, Those which do not possess true leaves, but only brownish scales, and have, if any, certainly very feeble powers of either imbibing food from without or of elaborating the nutritious ds obtained from other plants; and 2d, hich have true leaves furnished with and are capable of absorbing food here, and of elaborating that

NOTE V.

CONCLUSION.

SOME plants, instead of being fixed in the soil, are attached to other plants, from which they obtain, either wholly or in part, their nutriment. Of this parasitic vegetation there are two kinds, the first of which develop themselves in the inside of (living or dead) plants, and are consequently termed intestinal parasites; and having, for a time, thus grown, push above the surface. These are fungi, and some of them are well known under the names of mildew, smut, dryrot, &c. Those of the second division are called superficial parasites, since they originate upon the surface of plants. Having germinated there, the radicle penetrates the bark, and thus establishing a connection with the interior, the parasites withdraw for their own nourishment some of the sap of the plant on which they live. This division includes two kinds of parasites — 1st, Those which do not possess true leaves, but only brownish scales, and have, if any, certainly very feeble powers of either imbibing food from without or of elaborating the nutritious fluids obtained from other plants; and 2d, Those which have true leaves furnished with chlorophyll, and are capable of absorbing food from the atmosphere, and of elaborating that received from the vegetation upon which they grow. Another difference between these two divisions is, that while the parasites of the former class attach themselves to the roots, those of the latter fix themselves on the leaf or branch of the plant on which they have germinated. The different kinds of orobanche (parasitic upon broom, hemp, &c.) are examples of the brown scaly parasite, and the mistletoe is an example of the green parasite. In England there are not many important parasitic plants, but in warmer climates they are a striking feature in the vegetation, and very numerous. Some have handsome flowers, as the Rafflesias in Sumatra and Java; one of these, R. Arnoldi, bears flowers two and a half or three feet in diameter.

The parasitic plants must not be confounded with the Orchidaceæ, which grow upon living trees, and upon such dead ones as have fallen to the ground (and are, therefore, kept damp), for these have no connection with the interior of the plants on which they are found. Hence they are termed epiphytes.

A curious instance of, as it appears, abnormal nutrition is found in the case of a genus of the natural order Droseraceæ. The sun-dew has leaves furnished with glandular hairs and fringes, and with a sticky secretion which does not evaporate in strong sunlight, but remains like drops of dew upon the foliage throughout the longest summer day. An insect coming in contact with this juice becomes a prisoner, and the hairs upon the leaf then close round about it, or even the leaf itself curls up and gradually envelops it; and, as it is conjectured, the insect dying, the decay of its organism furnishes nutriment to the plant which has thus entrapped it.

We have now seen that, notwithstanding the great variety in vegetation, in the form, size, colour, texture, odour, taste, and chemical properties of vegetable matter, it is composed of but a few elements, the variation being the result of the plant's marvellous powers of analysis and synthesis.

The seed having germinated, and the embryo having been nourished by the seed contents provided by the parent plant, and with water and oxygen obtained from without, the young plant fixes itself in the ground by means of its roots, and puts forth its leaves. For its growth it requires a supply of suitable food, and this is brought to it by water and the atmosphere in a condition in which it can be imbibed—that is, in solution or in a gaseous state. From the soil the roots absorb water, in which are dissolved potash, lime, magnesia, oxides of iron, and soda, in the form of phosphates, nitrates, sulphates, carbonates, silicates, and chlorides, ammonia free and in combination, and carbonic acid; and the leaves, assisted by the other green parts of the plant, imbibe from the atmosphere carbonic acid, aqueous vapour, ammonia (nitric acid), and free oxygen. By processes unknown to us, these several compounds are decomposed; carbon is obtained from carbonic acid; nitrogen from ammonia and nitric acid; hydrogen from water, and perhaps from ammonia; oxygen from water, from carbonic acid, and from the air; sulphur from the salts of sulphuric acid; phosphorus from the salts of phosphoric acid; silicon from silicates; and chlorine from chlorides; and the base of each decomposed salt passes in the process of decomposition from one acid to another. The synthetical powers of the plant enable it to re-combine, in such combinations as are required, the elements thus obtained; other substances are formed by adding to and subtracting from these compounds, and still further changes are effected by so acting upon a body, that, although its chemical composition remains unaltered, so far as the quantity of its several constituents are concerned, it is transformed into a new substance, no longer possessing the chemical and physical properties which before characterised it. Thus a substance produced by the union of elements obtained from the decomposition of the food the soil and the atmosphere supply may undergo a lengthy series of changes or modifications in order that it may be of varied service to the plant, and the result is, that notwithstanding the comparatively limited number of the materials placed at the disposal of plants for the construction of their organism and their secretions, an almost endless variety is found in the substances produced by the processes of vegetable life.

The disintegration of rocks, the solution and subsequent deposition of mineral substances, and the decay of animal and vegetable matter, have formed the soil, and are the means by which its nutritive qualities are maintained. The sea is an indirect source whence an increase in the supply of mineral ingredients is obtained. When the waters of the ocean are tossed into the air, the wind catches the spray and carries it inland; here the course of the breeze is checked by the irregularities of the land, and the spray settles upon the earth, or the air is freed from the salts it bears by the rain which sweeps them down to the soil; and although the quantity of solid matter contained in sea-water is not large, the immensity of the surface from which it may be thus carried to the land renders it likely that plants derive a not inconsiderable supply of mineral substances through this channel.

The quantity and composition of the solid matter contained in a thousand parts of sea-water may be taken as—

Sodium chloride	26
Sodium sulphate	4
Potassium chloride	1
Magnesium chloride	5
Calcium sulphate	1
	37

together with traces of iodides, bromides, and other salts, and decaying organised matter.

The atmosphere is constantly receiving the gases necessary for the support of vegetable life: carbonic acid is being exhaled by animals day and night; ammonia is generated by the decay of animal and vegetable matter; and aqueous vapour is at all times mingling with the air from the evaporation of the waters of oceans, seas, and rivers.

When vegetation is allowed to remain where it has sprung up, it soon or late returns the materials it has made use of to the sources whence it obtained them. Thus in the autumn, the tree, having accomplished the work of the year, casts its leaves (which contain a greater quantity of fixed matter than any other part), and in Australia its bark; and when its life is at an end, dying upon the spot where it has lived, in its decay it gives back to the sources from which they were borrowed the substances used in the construction and sustentation of its organism.

The supply to the soil and to the atmosphere of those substances which plants require as food is, in this, the undisturbed condition of the earth, regular and unfailing, and in such a case the circle described by nutritive matter in its transit from one generation of growth to another is much shorter than where agricultural operations disturb the original relation between vegetation and the soil; yet, even when the plant is eaten by the grazing cattle or laid away in store for their winter use, or employed in the various ways in which vegetation is used for the support and comfort of man, the absence from the atmosphere and from the soil of the substances they have supplied for its nourishment is of but short duration. It is not for long that either animals or plants can withhold the sustenance each requires of the other.

Plants gather in food that has been formed by the decay of animal and vegetable matter, decompose and re-combine it, and store up within themselves the compounds they thus prepare for our use; we, in return, aid in the maintenance of vegetation by daily giving back, in a form acceptable to plants, some of the materials they selected for our support; and when we die, our substance fades away, and mingling with the gases of the air and the dust upon the earth, returns to the sources whence our caterers received the materials which had been employed in the formation of its organism and in the continuance of its functions;—thus passing still along that circle through which matter revolves for the maintenance of animal and vegetable life.

I need scarcely say how imperfect is our knowledge of the physiology of vegetation. The composition and chemical properties of vegetable matter, and of the substances from which materials for its construction are derived, have been ascertained, and we have a few data concerning the conditions under which these substances are obtained; but of the processes by which the decomposition and assimilation of food are effected we know little indeed. Notwithstanding the rapid strides with which chemistry, our pioneer, has advanced, and the attention devoted to the elucidation of our subject, we have in many instances to be content with ingenious hypothesis in place of scientific explanation.

The deeper we attempt to penetrate into the hidden wonders of vegetable life, and the more we see of the mysteries that become revealed, the less we feel to know. The strength of science shows to us our weakness. What we have learned in the ages that have passed away since first man strove to understand the workings of the universe, points out to us the littleness of all our human knowledge.

But it tells us of the perfect wisdom and boundless power that designed, and formed, and still maintains, the circle of created things. The more we learn of vegetable life, of its power and its purposes, of the complexity yet unfailing regularity of the arrangement of its parts, of its variations, almost illimitable in manner as in number, yet bound together in a oneness indestructible, the more wonderful to us does it become, the deeper lessons of trustful love does it impart. No branch of natural science more clearly evidences faultless design and unbounded power; nowhere is more clearly seen the unity of creation, the loving-kindness of its Creator. By the ever-varied and ever-changing beauty of its form and colour, vegetation adds in more than we can tell to the happiness of the life it is the means of supporting. While ministering to our necessities by the performance of processes upon the result of which the continuance of both animal and vegetable life depends, this flowery mantle, this poem-picture, so graceful in its winter outline, so charming in the colouring given to it by the sunny months, offers true lessons and brightening pleasure to the dwellers on the earth it so becomingly adorns.

The consideration of the design which binds together in an unbroken chain the living things of earth, makes one wish to lay aside for a time, at least, our human science, and think of that which science teaches—the greatness and the goodness of a loving God.

"Not a flower
But shows some touch in freckle, streak, or stain,
Of His unrivalled pencil. He inspires
Their balmy odours and imparts their hues,
And bathes their eyes with nectar; and includes
In grains, as countless as the sea-side sands,
The forms with which He sprinkles all the earth.
Happy who walks with Him, whom what he finds
Of flavour or of scent in fruit and flower,
Of what he views of beautiful or grand
In Nature, from the broad, majestic oak
To the green blade that twinkles in the sun,
Prompts with remembrance of a present God."

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